BULLETIN OF THE SCIENTIFIC LABORATORIES OF DENISON UNIVERSITY.
Vol. XII. Article IX. March, 1904.

GEOLOGICAL RELATIONS OF THE MANGANESE ORE DEPOSITS OF GEORGIA.[1]

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[1] Published by permission of the State Geologist of Georgia.

I wish to make acknowledgements to the various excellent maps and publications of the U. S. Geol. Survey, by Dr. C. W. Hayes, on the Georgia area; and to the valuable volume on "Manganese," by Dr. R. A. F. Penrose, issued by the Arkansas Geol. Survey, all of which have been freely used in the preparation of this paper.

Reprinted from *Transactions of the American Institute of Mining Engineers.* (Albany Meeting, February, 1903, 47 pages.)

[2] Omitted in the original paper.

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Introduction.

A part of the field-seasons of 1900, 1901 and 1902 was devoted by the writer to a study of the manganese ore-deposits of Georgia. A report embodying the results of this study is rapidly nearing completion, and when finished it will be published as a bulletin of the Geological Survey of Georgia. I believe, however, the importance of these deposits warrants a separate and earlier publication than that made possible by the Survey, in which the more important results of the study are briefly set forth. It is principally for this reason that the present paper has been prepared.

Previous Work.—Some of the more important deposits of manganese occurring in the Paleozoic area of Georgia were studied to some extent previous to 1890 by Dr. Penrose ;[1] and again in the early nineties by former State Geologist, J. W. Spencer.[2] In a recent paper published in the *Transactions*, on the "Geological Relations of the Iron-Ores in the Cartersville District, Georgia," Dr. Hayes[3] briefly mentions the manganese-ores of the same district.

Distribution of the Manganese-Ores.—Georgia is divisible into three geologically-distinct areas which, named in order from southeast to northwest, are (*a*), the Coastal Plain ; (*b*), the Crystalline Area ; and (*c*), the Paleozoic Group. The areas are sharply marked one from the other by two strongly defined structural lines. First, the fall-line, which crosses the State in a slightly south of west direction, passing through or near the cities of Augusta, Macon and Columbus, separates the Coastal Plain sediments on the southeast from the Crystalline area. And second, the Cartersville overthrust fault separates the Crystalline area from the Paleozoic area on the northwest. The position of both the fall line and the Cartersville fault are indicated on the sketch-map (Fig. 1) by the heavy broken lines.

The manganese ores are limited in occurrence to the northern part of the State, distributed irregularly to some extent over parts of both the Paleozoic and Crystalline areas. The commercially important deposits are confined to the northwestern part of the State in the Paleozoic area. Small shipments, not amounting to more than a few tons in all, have been made of ores mined in different parts of the Crystalline area. No deposits of manganese are yet known to occur within the limits of the Coastal Plain.

Fig. 1, a sketch-map of the northern half of Georgia, shows the distribution of the manganese-deposits in the State,

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[1] "Manganese : Its Uses, Ores and Deposits," *Annual Report of the Arkansas Geol. Survey*, vol. i, p. 417 *et seq.*

[2] "The Paleozoic Group," *Geol. Survey of Georgia*, 1893, pp. 190-209.

[3] *Trans.*, xxx., 403-419 (1901).

indicated by the solid black areas. The map further shows the outline of the areas covered by the Crystalline and Paleozoic rocks, and the extreme northwestern part of the Coastal Plain along the fall-line. That part of the Coastal Plain indicated on the map has its greatest width in a north-south direction along the eastern margin, extending south from Augusta.

The manganese-deposits of the two geologically different areas are best considered separately under I. The manganese-deposits of the Paleozoic area; and II. The manganese-deposits of the Crystalline area.

I. The Manganese-Deposits of the Paleozoic Area.

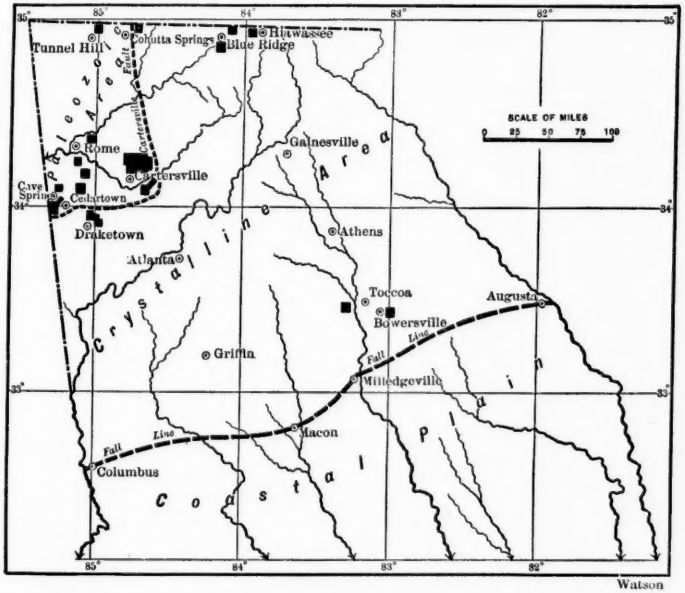
Résumé of the Geology of the Paleozoic Area.

Position.—The position of the Paleozoic area is shown on the accompanying map (Fig. 1). The area includes the ten northwest counties of the State, and is separated on the east and south from the Crystalline area by the Cartersville overthrust fault. It forms a part of the southern extension of the great Appalachian valley southwestward into Alabama.

Topography.—The region as defined above is a long, narrow belt in which the valley-type predominates, and the axis of which has a general northeast-southwest trend. When viewed in detail, it is observed to be composed of numerous subordinate valleys, separated by more or less extensive parallel ridges, whose axial directions are coincident with the general trend of the valley province. This ridge valley type of topography bears a definite relation to the rock-structure of the area. The ridges mark the lines of more resistant rock, while the valleys are etched out of the soft shales and limestones. According to the character of the rocks composing the ridges, and the position of the beds with respect to the horizon, the ridges are high or low, rather broad and flat-topped or narrow, and sharp-crested. The Knox dolomite, one of the most persistent formations in the area, and of intermediate hardness, forms a plateau of moderate elevation (between 900 and 950 ft. above mean-tide level) whose surface is gently undulating, usually not marked by any sharp ridges or peaks.

Traces of at least three rather distinct base-leveled plains appear in the region. According to Hayes[1] the highest and earliest one of these plains was probably formed during Cretaceous time, and the period of rest during which the atmospheric forces were operative is believed to have been much longer than that of the formative period of either one of the subsequent plains. The present streams were revived by the recent uplift, and they are now engaged in sinking their channels in the surface of the last base-level.

FIG. 1.



Sketch-Map of a Part of Georgia, Showing the Distribution of the Manganese-Deposits (Represented by the Black Areas).

Stratigraphy.—The rocks of the region range in age from lower Cambrian to Carboniferous, and they include slates, limestones, shales, sandstones and conglomerates. No igneous

[1] *Sixteenth Annual Report U. S. Geol. Survey*, 1895, Part III., pp. 553-554.

rocks are yet known to occur within the limits of the area. The manganese-deposits are limited to the residual decay resting on and derived from only three of the formations, namely, the Weisner quartzite, Beaver limestone and Knox dolomite. These formations are described in sufficient detail under the Cartersville and Cave Spring districts of this paper, and they need not be repeated here. (See Fig. 2).

Structure.—The region is one in which the strata have been thrown into great northeast-southwest folds from horizontal pressure applied in a northwest-southeast direction. In addition to the folding, continuation of the same compressive forces resulted in fracturing and faulting the strata over most of the area. To the northwest of the Coosa valley the area is one of open folds, and faulting is less conspicuous. Folds of the anticlinal, synclinal and monoclinal types are represented in many examples of northeast-southwest-trending ridges preserved in the harder and more resistant rocks.

In the region to the south and southwest of Rome, the structure is more complicated, largely by reason of the folding having been quite or entirely obliterated by subsequent faulting, and by deposition-overlaps and abrupt lithologic changes.[1] Two classes of faults, which differ materially from each other, characterize the area. These are designated by Hayes[2] as (*a*) major-thrust faults, and (*b*) minor-thrust faults.

The major-thrust faults are characterized by great horizontal displacement and low inclination of the fault-plane. Three faults of this type have been recognized and described by Hayes[3] in this area, namely, the Coosa, Rome and Cartersville overthrust faults. In the case of the Cartersville fault, rocks of probable Algonkian age and belonging to the Crystalline-

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[1] Hayes, C. W., *Bulletin, Geol. Soc. of America*, 1894, vol. v., p. 472.

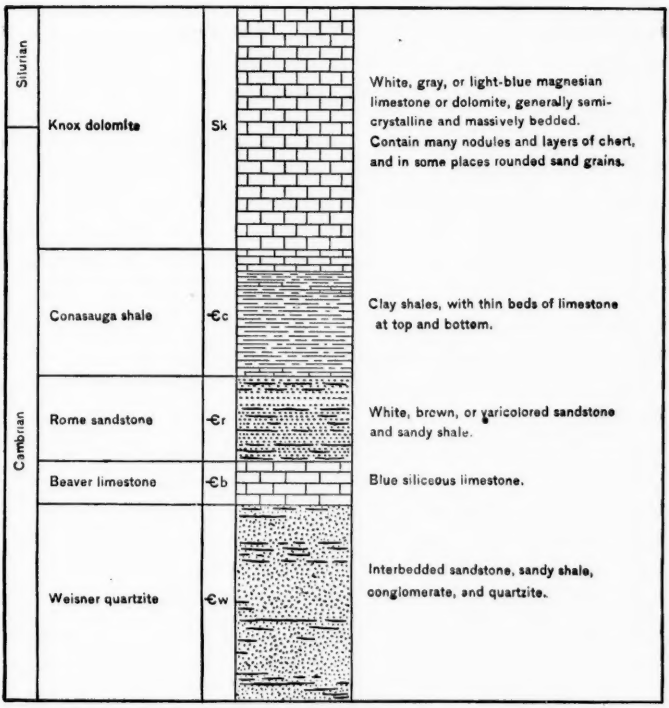
[2] *Op. cit.*, pp. 557-560.

[3] Hayes, C. W., "The Overthrust Faults of the Southern Appalachians," *Bulletin, Geol. Soc. of America*, 1891, vol. ii., pp. 141-154; "Geology of a Portion of the Coosa Valley in Georgia and Alabama," *Bulletin, Geol. Soc. of America*, 1894, vol. v., pp. 465-480.

metamorphic area of the State, have been overthrust upon Silurian rocks of the Paleozoic area. (See Fig. 3). These faults bear no relation to the manganese-deposits, and, therefore, need not be more fully described in the present connection.

The minor-thrust faults characterize the southern part of the area, especially of the area immediately south of Rome and in the vicinity of Cave Spring, and are of the ordinary Appa-

FIG. 2.


Silurian
Cambrian
Knox dolomite
Sk
White, gray, or light-blue magnesian limestone or dolomite, generally semi-crystalline and massively bedded. Contain many nodules and layers of chert, and in some places rounded sand grains.
Conasauga shale
Ec
Clay shales, with thin beds of limestone at top and bottom.
Rome sandstone
Er
White, brown, or varicolored sandstone and sandy shale.
Beaver limestone
Eb
Blue siliceous limestone.
Weisner quartzite
Ew
Interbedded sandstone, sandy shale, conglomerate, and quartzite.

Generalized Stratigraphic Section of the Georgia Manganese-Area. (Adopted from Hayes). Scale, approximately, 1 in. = 2000 ft.

lachian type. (See map of the Cave Spring district, Fig. 9.) They have an approximate north-south direction, intersecting the main axis of the region at angles of 30 to 40 degrees, or

thereabouts. In length they vary from 3 to 8 miles, and they cut the strata at close intervals into narrow strips, forming monoclinals, which dip steeply toward the east. The faults of this type in the region already mentioned result in long and narrow strips of the underlying Conasauga shales, which form the narrow valleys penetrating southward into the Knox dolomite plateau.

For the reason that the two types of faults here distinguished are seldom found intersecting each other, the faulting is inferred to belong to different and, therefore, distinct periods of disturbance.

The Cartersville District.

One of the principal manganese-producing districts in the Southern Appalachians is in the vicinity of Cartersville, Bartow county, Georgia, about 50 miles northwest of Atlanta. Manganese-mining in this district dates back as early as the year 1866, when 550 tons of the ore are reported to have been mined.[1] From that time to the present the Cartersville district has been one of the three principal producers of manganese in the United States. Excepting the Cave Spring district, the entire production of manganese in Georgia has been from this district.

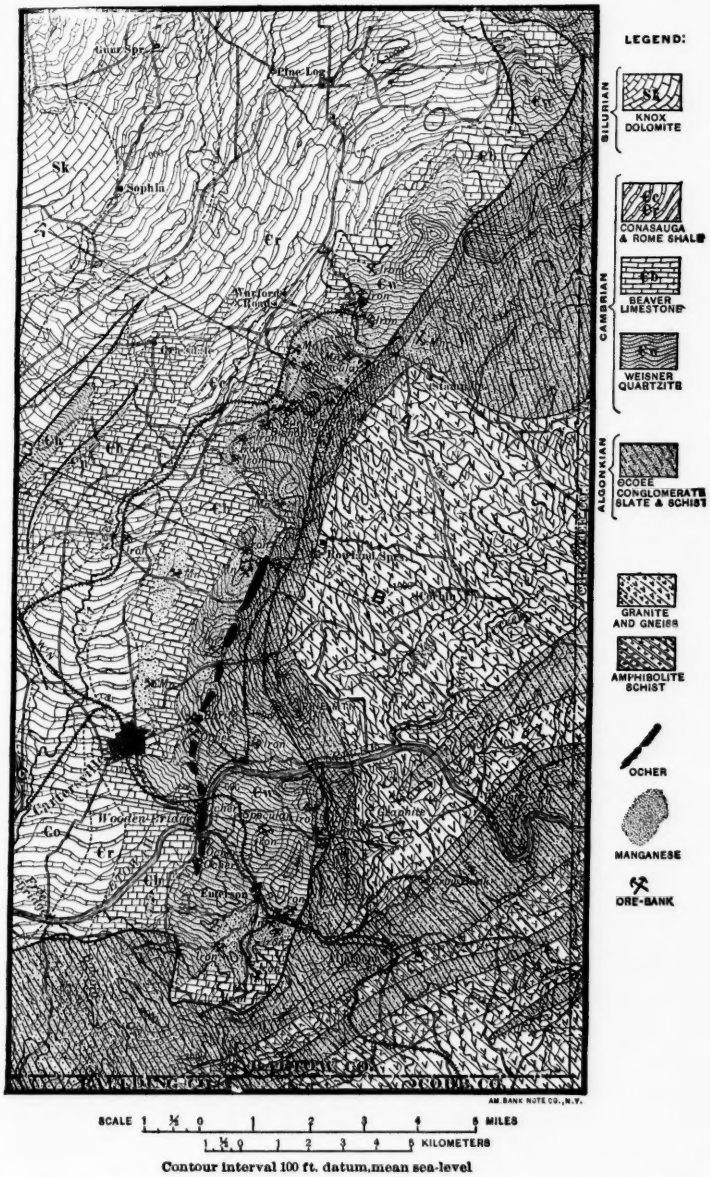
The older crystalline and metamorphic rocks occupy the east half of the area shown on the map (Fig. 3). The Paleozoic formations of the valley province occupy the west half of the mapped area. The line separating the two groups is an irregular one, marking the position of the Cartersville fault.

The succession of formations in ascending order, on the west side of the Cartersville fault, is as follows:

Silurian . .		Knox dolomite. Cherty magnesian limestone.
Cambrian,	Conasauga shale.	Olive clay shale, chiefly.
	Rome shale and sandstone.	Purple, white, green and brown sandstone, and interbedded sandy shale.
	Beaver limestone.	Blue siliceous limestone.
	Weisner quartzite.	Quartzite, coarse conglomerate and micaceous shale.

[1] *Mineral Resources of the United States*, 1885, p. 329.

FIG. 3.



Geological Map of the Cartersville District, Georgia, Showing the Distribution of the Ore-Deposits. (C. W. Hayes, *Trans.*, xxx., 465.)

Except the Knox dolomite, all the formations shown on the map to the west of the Cartersville fault belong to the middle and lower Cambrian. The Knox dolomite is here included entirely in the Silurian, although strong reasons appear for grouping the lower portion of this formation with the Cambrian. In Figs. 2, and 9, the Knox dolomite is designated as partly Cambrian and partly Silurian.

The Paleozoic Rocks of the Cartersville District on the West Side of the Fault.

The Weisner Quartzite.—The Weisner quartzite is in contact on the east side with the Cartersville fault. The principal area of the quartzite occupies the middle portion of the map as an irregular strip, having an approximate north-south extension of about 15 miles and, in width, varying from 1 to 3 miles. It is composed principally of a fine-grained quartzite, with additional bands of a fine-grained conglomerate and micaceous shales. Wherever exposed, the formation shows evidence of intense folding, fracturing and crushing. The absence of satisfactory exposures, added to the complex folding of the beds, prevents an accurate estimate of its total thickness, but it is probably not less than 2000 to 3000 ft. thick in this locality, as stated by Hayes.

Hand-specimens of the Weisner quartzite, carefully collected by the writer from the numerous outcrops of the entire area exposed in Georgia were thoroughly mixed and prepared as one sample, a representative part of which yielded, at the Pratt laboratory, Atlanta, the results shown below.

Analysis of Weisner Quartzite, Cartersville District.

SiO_2,	90.36
TiO_2,	0.07
Al_2O_3,	1.52
Fe_2O_3,	0.57
CaO,	0 27
MgO,	0.27
MnO,	None
Na_2O,	0.43
K_2O,	0.16

H_2O at 100° C.,	None
H_2O above 100° C.,	0.31
FeS_2,	1.50
$BaSO_4$,	4.46
Total,	99.92

The Beaver Limestone.—The main belt of the Beaver limestone lies along the western base of the Weisner quartzite ridges. A second, but smaller, area of the limestone extends from Grassdale southward to the line of the Western and Atlantic railroad, and is indicated near the western margin of the map. Exposures of the fresh limestone are rarely seen, since it is readily soluble, resulting in the insoluble residue forming a thick mantle of deep-red soil. The formation is readily traced, however, from the resulting red soil. Fragments of the quartzite in all stages of decay, derived from the adjacent higher quartzite ridges on the east, are admixed in some quantity with the decay derived from the limestone. The few exposures of the limestone met with indicate a semi-crystalline, gray, magnesian limestone, containing, as Hayes states, occasional masses of chert, becoming shaly in places. Hayes[1] estimates the thickness of the limestone to be not less than 800 to 1200 ft.

These two formations, the Weisner quartzite and Beaver limestone, are of considerable importance as ore-producing formations in the Cartersville district, as a majority of the ore-deposits are associated with them. The manganese-ores occur with about equal frequency in the residual decay of the two formations.

The Conasauga Shale.—Next above the Beaver limestone is the great thickness of the Rome and Conasauga sandstone and shale (Oostanaula shales of Spencer). The main outcrop of the shale occupies the northwestern part of the mapped area. A continuous band of the exposed shale extends southward from the main outcrop to the line marking the position of the Cartersville fault. The southern half of the band, which extends several miles in a north, south and west direction from Cartersville, is greatly widened.

[1] *Trans.*, xxx., 406 (1901).

Petit creek, one of the principal streams in the area mapped, takes its rise in the Conasauga shales some 10 miles north of Cartersville, and maintains its entire course southward to the Etowah river on the soft shales.

In lithologic character, the shales vary from very fine-grained aluminous or clayey rocks to somewhat siliceous shales and sandstone, with the aluminous type predominant. Numerous exposures show interlayered thin- and thick-bedded limestone with the shale. In color, the shales vary from light-drab and yellow to dark blue slaty, best described, as a whole, as olive shales. The weathered shale is usually tinted some light shade of red, in marked contrast to the deep red decay of the limestone. The shales are much fractured and crushed from the effects of intense pressure metamorphism. The thickness of the formation is placed between 1500 and 3000 ft.

The following analyses give a general idea of the chemical composition of the shales in this region:

Analyses of Middle Cambrian Shales, Cartersville District.

	I.	II.	III.	IV.	V.
SiO_2, (free sand), SiO_2, (combined),	55.02	52.82	62.30 / 9.30	39.20 / 19.40	52.82
Al_2O_3,	21.02	26.17	11.50	18.05	26.17
Fe_2O_3,	5.00	9.46	5.59	8.31	9 46
FeO,	1 54	----	----	----	----
MnO,	trace	----	0.60	----	----
CaO,	1.60	trace	none	none	trace
MgO,	2.32	1.08	1.30	1.55	1.08
Na_2O,	0.81	0.20	0.35	0.33	0.20
K_2O,	3.19	2.71	4.20	4.63	2.71
H_2O at 110° C.,	2.44	0.23 (hygr.)	0.15 (hygr.)	0.40 (hygr.)	0.23 (hygr.)
H_2O above 110° C.,	5.65	7.00	3.80	7.60	7.00
TiO_2,	0.65	----	1.10	0.68	----
P_2O_5,	0.06	----	----	----	----
BaO,	0.04	----	----	----	----
SrO,	trace	----	----	----	----
Li_2O,	0.03	----	----	----	----
SO_3,	0.02	----	----	----	----
Cl,	trace	----	----	----	----
CO_2,	0.83	----	----	----	----
Carbonaceous matter,	0.32	----	----	----	----
Total,	100.54	99.67	100.19	100.15	99 67

I. Middle Cambrian shale. Coosa Valley, near Blaine, Cherokee county, Alabama. H. N. Stokes, analyst. *Bulletin No.* 163, *U. S. Geol. Survey*, 1900, p. 283.

II. Oostanaula (Conasauga) shales, about 2 miles northwest of Cartersville, Bartow county, Georgia. J. M. McCandless, analyst. "Paleozoic Group," *Geol. Survey of Georgia*, 1893, p. 285.

III. Light-colored hydro-mica shale on the ridge above the Etowah river iron bridge, south of Cartersville. On the border of the metamorphic zone. "Paleozoic Group," *Geol. Survey of Georgia*, 1893, p. 284. J. M. McCandless, analyst.

IV. Light-red shale, in the valley 1 mile southwest of Cartersville. "Paleozoic Group," *Geol. Survey of Georgia*, 1893, p. 284. J. M. McCandless, analyst.

V. Oostanaula (Conasauga) shales, about 2 miles northwest of Cartersville. "Paleozoic Group, *Geol. Survey of Georgia*, 1893, p. 285. J. M. McCandless, analyst.

The Knox Dolomite.—The Knox dolomite lies next above the Conasauga shales. The lower beds are probably Cambrian, but, owing to the paucity of fossils in them and the striking uniformity in lithologic character, the entire formation is here classed as Silurian. Hayes says:[1]

"From the few fossils which have been found, it appears probable that a transition from Cambrian to Silurian occurs in the lower third of the formation, but it is generally impossible to determine this line of division. . . ."

It is a massively-bedded, semi-crystalline, gray-magnesian limestone, containing abundant nodules and layers of chert, and is one of the most persistent formations in the Southern Appalachians.

Weathering of the dolomite, by removal in solution of the soluble calcium and magnesian carbonates, has covered the limestone surface by a prevailingly thick mantle of insoluble siliceous clays abundantly admixed with chert-fragments and masses. The residual clays derived from the dolomite are often light in color, containing comparatively small amounts of iron oxide. In many places, however, the clays derived from the limestone are deep-red ferruginous clays, containing much iron oxide. The proportion of clay to chert varies considera-

[1] "Geologic Atlas of the United States," Rome Folio, *U. S. Geol. Survey*, 1902, p. 3.

bly, but the quantity of chert admixed with the clay is always large. It is by means of its residual material, especially the chert nodules and masses, that the Knox dolomite is often traced, for exposures of the fresh rock are seldom seen except along the stream-courses.

The magnesian limestone has an estimated thickness of 3000 to 5000 ft. As a producer of manganese-ores, the Knox formation is, perhaps, of less importance in the immediate Cartersville district than either the Weisner quartzite or Beaver limestone. Excepting the Cartersville district, the Knox dolomite is one of the most important ore-producing formations in the Georgia Paleozoic area, as the extensive accumulations of bauxite and a part of the iron- and manganese-deposits are associated with it.

The numerous chemical analyses made from specimens collected from the Knox formation over many localities in Georgia show its composition to vary within the following limits:

SiO_2, 3.75 to 7.25; Al_2O_3 and Fe_2O_3, 1.24 to 1.76; $CaCO_3$, 34.07 to 53.44; and $MgCO_3$, 36.32 to 55.74 per cent.

The Older Crystalline and Metamorphic Rocks of the Cartersville District on the East Side of the Cartersville Fault.

Several types of crystalline, metamorphic rocks are represented which show wide variation in composition and, probably, in age. Of these, the Corbin granite-area, which occupies the middle eastern portion of the map (Fig. 3), is the most extensive. As mapped, this granite mass is a roughly oval-shaped area extending from Stamp Creek P. O. on the north to the line of the Western and Atlantic railroad on the south, and continuing eastward into Cherokee county. The granite is a coarse-grained porphyritic rock, presenting a distinct augen-gneiss facies in the border-portions. It is composed of large, microcline phenocrysts imbedded in a ground-mass of blue quartz, plagioclase feldspar, augite and mica. Its composition is shown in the following analysis, made by Dr. H. N. Stokes,

of specimens collected by Mr. A. H. Brooks of the U. S. Geological Survey, 1 mile east of Rowland, Bartow county, Georgia:

Analysis of Granite, Cartersville District.

SiO_2,	67.98	TiO_2,	0.84
Al_2O_3,	14.84	P_2O_5,	0 34
Fe_2O_3	1.00	MnO,	trace
FeO,	3.15	BaO,	0.20
MgO,	0.91	SrO,	trace
CaO,	2.17	Li_2O,	trace
Na_2O,	2.66	S,	0.08
K_2O,	4.76	Cl,	trace
H_2O+,	0.14	F,	trace
H_2O-,	0.49	C (Graphite),	0.21
		Total,	99.77

Brooks has given the following petrographic data on the granite from this locality:

"Contains microline, some plagioclase, abundant pyroxene, partly altered into chiefly uralite and chlorite, some biotite with frequent inclusions of rutile, much blue vitreous quartz, apatite, zircon and magnetite."[1]

In places, the border-portion of the granite mass is overlapped by a coarse feldspathic conglomerate whose mineral constituents were evidently derived from the granite, since the microcline and the blue quartz of the granite enter largely into the composition of the conglomerate. In other places a series of black graphitic slates are in contact with the granite. No fossils are known to occur in the conglomerates and slates, and on account of their appearance of extreme age, Hayes[2] has grouped them as Algonkian (Ocoee).

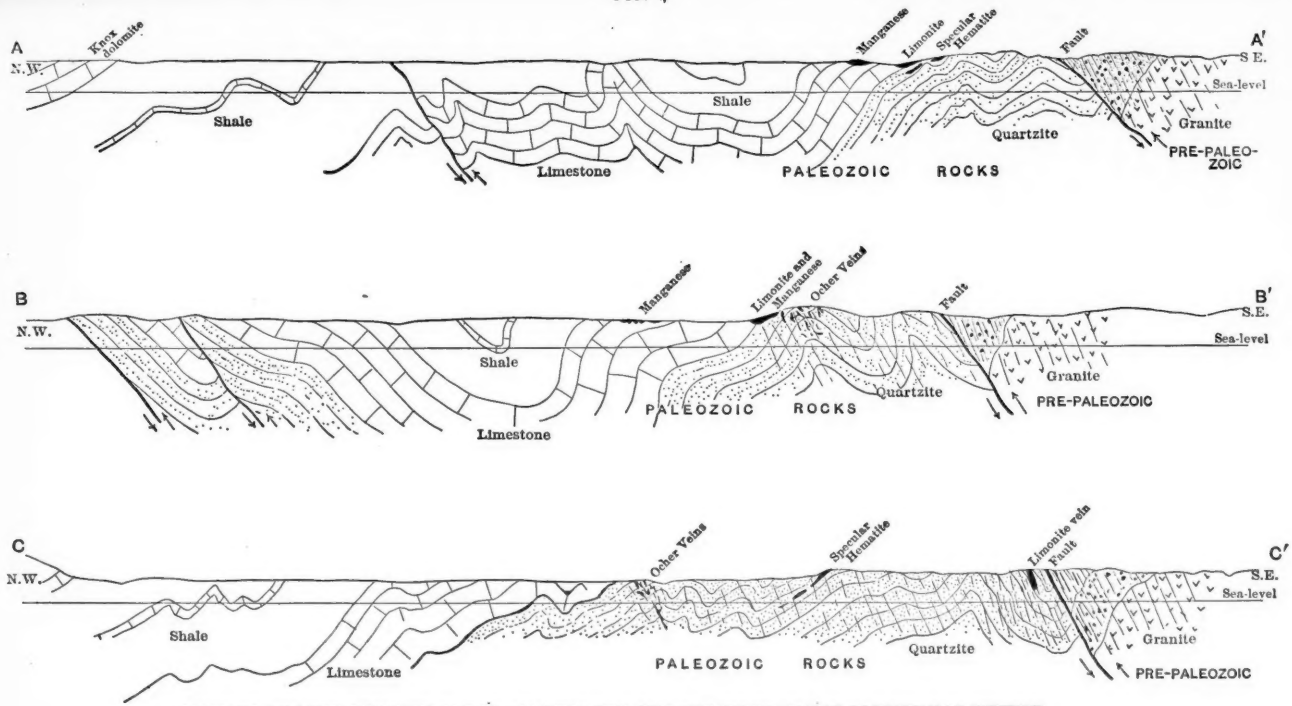
To the south of the Corbin granite-area, the conglomerates and slates increase in metamorphism and apparently pass into schists and gneisses, whose origin, whether igneous or sedimentary, is unknown.

The extreme southeast corner of the map (Fig. 3) comprises narrow belts of granite, gneiss and hornblende (amphibo-

[1] Clarke, F. W., *Bulletin, U. S. Geol. Survey*, No. 168, 1900, p. 55.

[2] Hayes, C. W., *Trans.*, xxx., 408 (1901).

FIG. 4



SECTIONS ON LINES INDICATED IN FIG.3., SHOWING GEOLOGIC STRUCTURE OF THE CARTERSVILLE DISTRICT.

Scale, horizontal and vertical 1 in. 5000 ft.

Section on Lines Indicated in Fig. 3, Showing Geologic Structure of the Cartersville District. (C. W. Hayes, *Trans.*, xxx., 407.)

Scale, horizontal and vertical, 1 in. = 5000 ft.

lite) schist. According to Hayes,[1] both diabases and diorites are represented in the area. Diorite is regarded as the commonest type of rock, and it is now mostly altered into the amphibolite schist.

Structural Features.

It is only necessary in this paper briefly to call attention to the broader structural features of the district, since the manganese deposits are limited to the residual clays of several of the formations, and only in a very general way do they show any relations to the structure. In his paper on the iron ore-deposits of the district, Hayes has discussed in some detail and in a most excellent manner the structure of the region, to which paper the reader is referred for further details.[2]

The area has been one of intense and prolonged disturbance (compressive forces) operating in a northwest-southeast direction, resulting in profound alteration of the rocks,—their folding, crushing and fracturing. In places, some of the rocks, originally unlike, are so profoundly altered that they are with great difficulty distinguishable at present. On the east side of the fault-line the rocks are mashed and squeezed, and the slaty and schistose structures strongly developed, while on the west side the rocks are complexly folded and fractured. In addition to the folding, the Weisner quartzite especially has been much crushed and in places brecciated, probably indicating faulting. Some of the more massive formations, such as the Knox dolomite, resisted the folding to a greater degree than others.

The overthrust fault which separates the older crystalline rocks from the Paleozoic sediments is the principal structural feature of the region. Its position is shown on the accompanying map (Fig. 3), where it is observed to pass some distance to the east and south of Cartersville, from which town it derives its name. Its line of contact is here marked by the rocks of the Ocoee series on the east side, brought next to the rocks of the Cambrian on the west side.

[1] *Ibid.*, p. 408.

[2] *Op. cit.*, pp. 403-419.

The Manganese Ore-Deposits of the Cartersville District.

Mode of Occurrence of the Ores.—The manganese-ores occur imbedded in the heavy mantle of residual material derived from the decay of the Beaver limestone and the Weisner quartzite, and they have nearly equal distribution in the decay de-

FIG. 5.

Topographical Map of the Cartersville District, Georgia. (Cartersville Topographic Sheet, *U. S. Geol. Survey*). Contour-interval, 100 ft.

rived from the two formations. The decay of the Weisner quartzite is a gray to yellow siliceous clay admixed with fragments of the quartzite in all stages of decay; that of the Beaver limestone is a deep-red clay, less siliceous than that derived from the Weisner formation, admixed with some chert-fragments; and, near its eastern margin in contact with the Weisner quartzite, additional fragments of the latter rock are found.

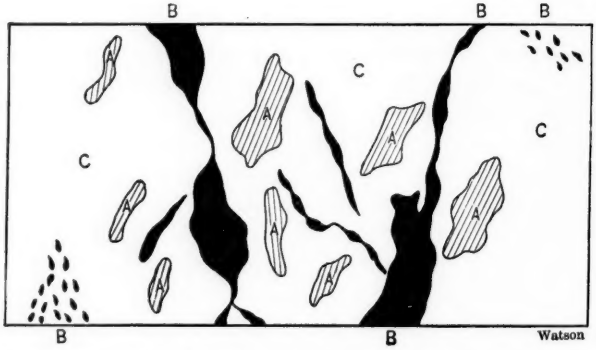
The ore is distributed through the clays in an extremely irregular manner in the form of pockets or lenticular masses, rarely as distinct beds; veins and stringers cutting the clays in all directions; as single nodules or concretionary masses assembled in the clays; and as small disseminated grains scattered through the clay. In places, the ore-distribution in the clays conforms in a general way to the bedding of the inclosing clays; usually, however, this is obscured and the ore-bodies indiscriminately cut in all directions. The pockets vary widely in size and number. They range in size from mere nests to bodies 6 and more ft. thick and more than 30 ft. long, and in extreme cases may yield several hundred tons of ore. Rarely are they composed of solid ore free from the surrounding clay, the usual form being that of somewhat thickly-studded nodules in the clays. They may occur close together, or far apart, and are usually not in any way connected; although in many cases irregular stringers and small veins are observed to lead from one pocket to another. (See Figs. 6 and 7.)

The ores are never entirely free from inclusions and admixtures of the inclosing clays, a condition which naturally results from their method of accumulation. Some of the ores are, of course, freer from these mechanical impurities than others, and in the purest ore the included grains of silica and the adhering clay are reduced to a minimum. The proportion of clay to ore is usually larger than in the closely associated brown iron-ores.

Depth of the Residual Decay.—The depth of the rock-decay varies greatly, and it is dependant, other things being equal, on the character and composition of the rock, and on the disposition of the rock-strata. The quartzite of the Car

tersville district has been much broken and crushed, and it is thrown into a series of narrow, more or less steep folds or ridges, whose surface is everywhere covered to some depth with its residual decay. Reefs of the hard and fresh rock are often exposed along the crests of the ridges, and to some extent exposures are frequent near the tops and along the steeper slopes of the ridges.

FIG. 6.



Section in One of the Openings on the Blue Ridge Mining Co.'s Property, near Cartersville, Georgia, Showing the Mode of Occurrence of the Manganese-Ore in the Residual Clay.

A, fragments and masses of partially decayed rock; B, manganese ore; C, residual clay.

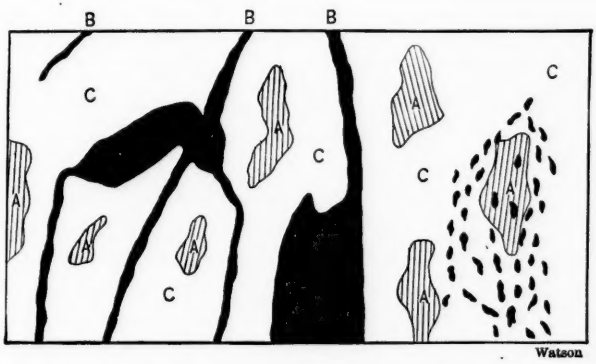
Horizontal and vertical scale, 1 in. = 17 ft.

Shafts have been sunk in several places to a depth of several hundred feet without piercing the bed-rock. Depths of 100 ft. and more in the residual mantle are common in the district. In the Chumler Hill section, about 8 miles northeast of Cartersville, several shafts have been sunk to a depth of more than 80 ft. in manganese-mining without encountering the bed-rock. (See Fig. 11.)

Kinds of Ore.—Only the oxides of manganese occur in the Cartersville district. Of these, pyrolusite and psilomelane greatly predominate, with some manganite and braunite and much of the earthy oxide, wad. These different oxides cannot always be separated, but they usually occur admixed in vary-

ing proportions. With the exception of the mineral wad, the ore is usually partially or entirely crystalline, of a dark steel-blue color, and the nodular type which prevails nearly always displays the complete or partially layered or concentric structure of concretionary masses.

FIG. 7.



Section in One of the Openings at the Dobbins Mine, near Cartersville, Georgia, Showing the Occurrence of Manganese-Ore in the Residual Clays. (Modified from Penrose.)

A, fragments and masses of partially decayed rock; B, manganese-ore; C, residual clay.

Horizontal and vertical scale, 1 in. = 10 ft.

Associated Ore-Deposits.—Extensive deposits of brown iron-ore and gray or specular hematite, yellow ocher, and to a less extent barite and bauxite occur somewhat closely associated with the manganese-ores. Of these the deposits of iron-ore and yellow ocher have been extensively mined. The bauxite and barite are of less importance, since the former is only sparingly found within the limits of the district, and the latter, while more abundant, is not sufficiently concentrated to admit of profitable working. These are again referred to at some length in a subsequent part of this paper under the origin of the manganese-ores.

Manganiferous Iron-Ores.—The beds of brown iron-ore, which is the prevailing type of iron-deposit in the district, are usually distinct from, though occurring in close relation with,

the manganese-ores. The oxides of iron and manganese are often found admixed in different proportions in the same bed. Between the two extremes of pure iron-ore and pure manganese-ore occur all gradations in the admixture of the two oxides. In some of the beds the two materials are homogeneously mixed, giving the appearance of a manganese ore when the iron is present in small quantity, and of the usual brown hematite-ore when manganese is in small quantity. In still other cases the beds of iron-ore are found incrusted in places at the surface for only a slight depth, with the oxide of manganese, which on being opened proves to be a good deposit of iron-ore and not manganese.

Analyses of the iron-ores invariably show small percentages of manganese, and conversely the manganese-ores show varying percentages of iron, with intermediate gradations in which the two oxides are present in nearly equal amount, forming a good grade of manganiferous iron-ore. These gradations are shown to some extent in the following partial analyses of samples of the ores from this district:

Analyses of Cartersville Iron- and Manganese-Ores.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Manganese, -	41.98	36.00	25,09	15.26	60.61	2.30	54.94	56.40
Iron, -	16.22	16.88	29.17	39.25	1.45	52.02	3.62	1.29
Phosphorus, -	0.227	0.14	0.155	0.193	0.052	0 24	0.034	0.158

Chemical Composition. — The hundreds of commercial analyses of the Cartersville manganese ores indicate that the ores do not differ essentially from similar high grade ores occurring elsewhere. The average in metallic manganese in the better-grade ores is uniformly high, with correspondingly low iron, silica and phosphorus. Silica will usually average low in those cases where the ore has been properly cleansed. It rarely ranges above 10 per cent., and is usually much below this, averaging from 2 to 5 per cent. Of course, in many of the lower-grade ores the silica will average considerably above 10 per cent. The phosphorus in the Cartersville ores is rarely high enough to detract from the value of the ore. The average in this ingredient for the better-grade ores of the district is

from 0.10 per cent. to 0.15 per cent., rarely rising above 0.25 per cent.

Individual Properties.—No attempt will be made in this paper to discuss or describe individual properties. These will be described in detail in a forthcoming report by the writer, to be published by the Geological Survey of Georgia. Among some of the more important properties in the district which have yielded much ore of superior quality may be mentioned the Blue Ridge Mining Company (formerly known as the Etowah Mining Company), the Dobbins, the Georgia Manganese and Iron Company, the Milner-Harris, the Satterfield, the John P. Stegall, the Chumler Hill and the Southern Mining Company. Innumerable single lots of land, distributed over all parts of the district and owned by different individuals, have produced large quantities of high-grade ore, but the lack of space forbids their mention by name.

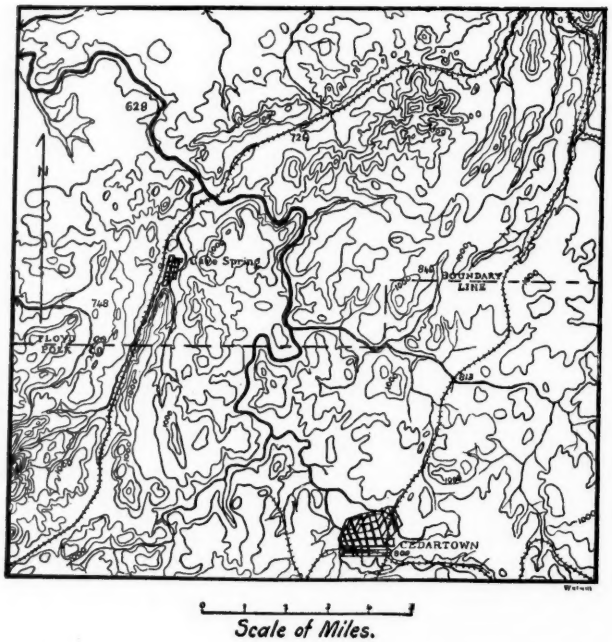
The Cave Spring District.

The Cave Spring district occupies the southwest part of Floyd county and the northwest corner of Polk county, Georgia. The town of Cave Spring, from which the district takes its name, is within six miles of the Alabama-Georgia line, about 15 miles southwest of Rome. The ore-deposits of manganese extend about 5 miles south of the town into Polk county, and continue northeastward from the town for a distance of 7 or 8 miles in Floyd county. Practically the entire production of manganese ores in Georgia has been from the Cartersville and Cave Spring districts.

Topography.—The topography of the Cave Spring area is shown on the accompanying map (Fig. 8). The region is one in which the topography is strikingly shown to be dependent on the structure and character of the underlying rocks. The strata are broken by numerous approximate north-south faults of the ordinary Appalachian type, resulting in monoclinal blocks, which dip somewhat steeply to the east and southeast. Faulting has brought the underlying shale to the surface in contact with the overlying Knox dolomite, and valleys are

etched out of the soft shale, penetrating to some extent the harder and more resistant Knox dolomite. These features are well developed in the vicinity of Cave Spring and are shown again in the northeast corner of the map (Fig. 9).

FIG. 8.

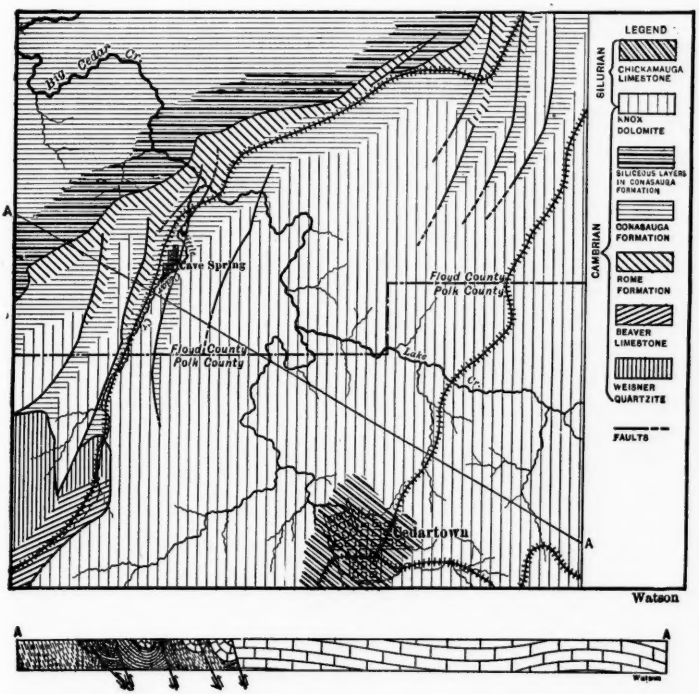


Topographical Map of the Cave Spring District, Georgia. (Topographic Sheet, Rome Folio, *U. S. Geol. Survey*). Cont ur-interval, 100 ft. Scale, 0.5 in. = 1 mile.

To the east of a line drawn through the town of Cave Spring the area is underlaid by the Knox dolomite. Surface-erosion is relatively slower over this part of the area, on account of the larger proportion of chert contained in the dolomite, than in other parts underlain by softer and less resistaut rocks. The surface is generally hilly and stands several hundred feet above the valley-floors of softer rock. It forms a

broad plateau, averaging slightly below 1000 ft. in elevation. In the extreme southwest corner of the map (Fig. 9), the hard and resistant massive Weisner quartzite is exposed as a high ridge, known as Indian mountain, which lies almost entirely in Alabama. Traces of the same base-levels are preserved in the rocks of this area as those mentioned in the region farther north.

FIG. 9.



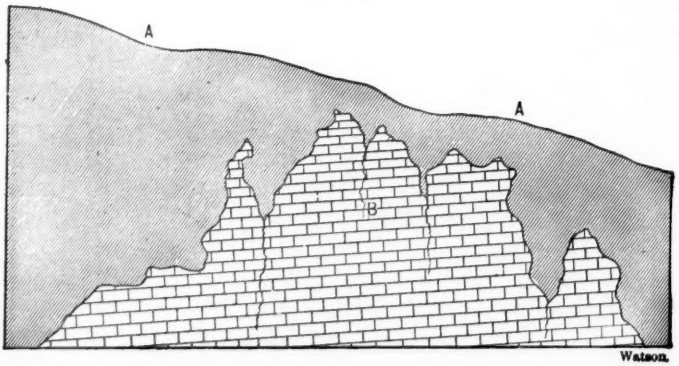
Geological Map and Section of the Cave Spring District, Georgia. (Rome Folio, *U. S. Geol. Survey.*)
Scale, 0.5 in. = 1 mile.

Stratigraphy.—The same rock-sequence is observed here as in the Cartersville area. (See Fig. 2). The same formations are represented in the two areas, with only slight varia-

tions indicated in the general character and thickness of the rocks. These formations have been described in sufficient detail under the Cartersville district, and will not be repeated here. The Knox dolomite of the Cave Spring district needs further description, since it is the only formation in the area with which the manganese-ores are associated.

The Knox dolomite is vastly the most extensive formation in the district. The percentage of chert is much larger, and the cherty masses and fragments are larger in size than elsewhere for this formation. In places, the limestone appears to be largely replaced by layers of the massive chert. Its surface is very generally strewn with the chert, and the deep-red clays derived from the limestone are heavily charged with the chert-fragments in all stages of decay.

FIG. 10.



Section in Knox Dolomite, 2 miles East of Kingston, Georgia, Illustrating Weathering of the Magnesian Limestone. (Modified from Spencer.)
A, residual clay; B, fresh magnesian limestone.

Structure.—Referring again to the map (Fig. 9), it is observed that nearly the entire southeast part is occupied by the massive Knox dolomite, which resisted the sharp folding manifested in some of the other formations. The remaining part of the map indicates numerous faults cutting the strata. These are mostly of the minor-thrust type, intersecting the Knox dolomite and the Conasauga shale, and they expose at the sur-

face the soft shales in long and narrow north-south strips, forming narrow valleys among the dolomite hills. The fault-blocks overlap each other, with rather steep dips toward the east and southeast.

Character of the Residual Decay.—The manganese ores of the Cave Spring area are entirely limited to the residual clays derived from the decay of the Knox dolomite. The decay from this formation only will be considered. The ore-bearing clay is usually of a deep-red, chocolate or brown color, with lighter tints occurring. It is soft and plastic when wet, and is generally associated with much siliceous material in the form of chert, subject to wide variation from place to place. Its depth is variable and, in places, the moderately fresh cherty limestone is exposed as broken reefs on the ridge-tops. In other places on the ridge-tops, excavations in mining expose the hard rock at depths varying from 10 to 30 ft.; and, in still other places on the same ridges, rock is not encountered at depths of 50 to 60 ft.

Massive cherty layers or beds are of more frequent occurrence in the limestone of this area than for the same formation at other points in northwest Georgia. Here the chert attains considerable thickness, and, at times, almost entirely replaces the limestone. Uusually the chert is a white or gray rock, sometimes brown, rarely black, and is often encrusted with a film or coating of the black oxide of manganese. The relation of the chert and limestone is well illustrated along the ridges to the southeast of the town of Cave Spring, where the rocks dip to the southeast, with the limestone forming the lower part of the hills and the chert the upper part.

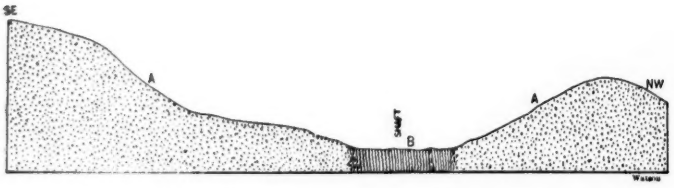
Manganiferous Chert Breccia.—The very intimate association of the chert and ore has resulted in the formation of much breccia, composed of the angular chert-fragments cemented in a manganese-oxide matrix. This seems to have originated in most cases from the infiltration of surface-waters containing manganese in solution. The occurrence of the chert-breccia beneath the clay covering is excellently illustrated in some of the excavations on the ridge above the Cedar creek valley, and

again in the openings on Reynolds mountain, 8 miles northeast of Cave Spring. (See Fig. 15.)

Manganiferous Stained Chert.—Where the chert is mixed in large proportion with the ore-bearing clays, it is often more or less stained with the manganese. This may occur as thin films or layers of the manganese oxide coating the loose chert-fragments, or as stringers and veinlets filling the cracks in the chert. The proportion of staining to chert is quite variable. In many cases it amounts to only a mere film; in others, the veins filling the cracks are quite thick. This has resulted from the free percolation of manganese-bearing waters through the loose cherty clays. Sometimes, that part of the chert not impregnated has been entirely or partially removed by decay, leaving a mass of siliceous manganese-ore of various shapes.

Occurrence of the Ores.—The occurrence of the manganese in this area is closely similar to that in the Cartersville district, already described. (See Figs. 6, 7 and 15.) The ores differ

FIG. 11



Section through the Chumler Hill Mine, Georgia, Showing the Mode of Occurrence of the Manganese-Bearing Clay. (After Penrose.)
A, sandstone; B, manganese-bearing clay.
Horizontal scale, 1 in. = ¼ mile. Vertical scale, 1 in. = 400 ft.

principally in occurrence from those in the Cartersville district in (*a*) their intimate association with the cherty beds and clays of the upper part of the Knox dolomite, in (*b*) being limited to the residual clays derived from only one formation, and (*c*) being stratigraphically above those of the Cartersville district, occurring in the clays of the Knox dolomite and not found at all in the clays of the Weisner quartzite and Beaver limestone,

which are the ore-bearing formations in the Cartersville district. The ore-occurrence in the residual clays is identical for the two districts. In the Cave Spring district the ore has been observed penetrating and filling the cracks in the partially decayed rock below in all directions with much the appearance of brecciated masses.

Associated Ore-Deposits.—Beds of brown iron-ore are frequently found in close relation with the manganese-ores. They are much more extensive and more constant than those of manganese, and the iron displays a greater tendency to a bedded form and a less tendency to the nodular form. The region in the vicinity of Cave Spring and Cedartown is probably the largest brown iron-ore-producing area in the State. A few scattered deposits of bauxite occur, but this mineral is less closely associated with the manganese than are the beds of iron-ore.

Chemical Composition.—Only the oxides of the metal occur, the principal ones of which are psilomelane and pyrolusite. Admixed with these two oxides occur varying smaller percentages of several of the other oxides, especially braunite. The following chemical analysis of specimens of the purer ore collected from the mine of Major Couper, south of Cave Spring, and analyzed by Mr. Britton, will indicate the general character of the ores.

Analysis of Manganese-Ore, Cave Spring.

Metallic manganese,	53.44
Ferric oxide,	2.83
Barium oxide,	8.62
Silica,	7.79
Alumina,	1.52
Lime,	0.08
Phosphoric acid,	0.147
Water,	1.56
Oxygen with manganese, undet., etc.,	24.013
Total,	100.000

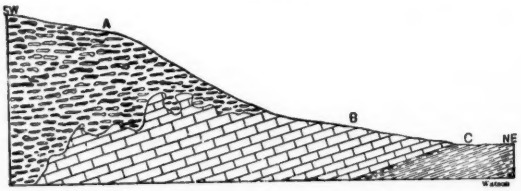
Other Manganese-Deposits of the Paleozoic Group.

Under this heading are included certain centers about which are grouped a few scattered deposits of manganese-ores.

These centers are found over parts of the northeastern, eastern and southern portions of the Paleozoic area. Many of the deposits have been worked to some extent, but in most cases the work has not progressed beyond the stage of test-openings. In some cases, no openings of any nature have been made, but strong surface-indications appear, which may or may not imply workable deposits below the surface. Small shipments of the ore have been made from a number of the openings, but as yet these scattered accumulations of the ore have proved of little or no commercial importance. Further developments in some of the localities may, perhaps, lead to important concentrations of workable ore. The mode of occurrence, association and the mineral character and form of the ores are the same as described in the Cartersville and Cave Spring districts.

The following localities include the list of these scattered ores: In the vicinity of Ligon P. O., in the extreme southwest corner of Bartow county, about 12 miles west of Cartersville; near Rome and Lindale, in Floyd county; in Big Texas Valley, 12 miles northwest of Rome, in Floyd county; the Barns-

FIG. 12



Section through the Barnsley Tract, Georgia, Showing Manganese-Bearing Chert-Bed. (Modified from Penrose.)
A, chert and cherty limestone; B, limestone; C, shale.
Horizontal scale, 1 in. = 500 ft. Vertical scale, 1 in. = 200 ft.

ley estate and vicinity, in the northwest part of Bartow county and the adjacent part of Floyd county, 17 miles northwest of Cartersville; and the Tunnel Hill district, in Whitfield and Catoosa counties.

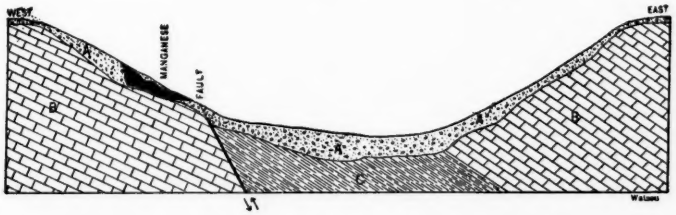
Attention is briefly called to the deposits in two of these localities.

The Lindale Deposit.—Extending southward from Lindale

is a long, narrow strip or belt of shale which marks the position of a valley for several miles in a north-south direction. The western margin of the valley marks the position of a minor-thrust fault, and to the eastward across the valley, about ¼ of a mile, the shales are overlain by the heavy beds of cherty limestone. The ridge is a low one, averaging more than 100 ft. in elevation along its highest portions, and its surface is irregular and broken by erosion. In places, it is covered with chert-fragments of all sizes in various stages of decay. (See Figs. 13 and 14.)

About ¾ of a mile south of Lindale, on the west slope of the valley and about 40 ft. above the valley-bottom, a number of openings were made in the residual cherty clay, derived from the decay of the Knox dolomite, for manganese. Red, yellow, white, buff and purple-colored clays make up the residual covering in which the manganese openings were dug. Red clay is the surface covering, and will average less than 5 ft. in thickness. The underlying yellow clay which predominates is

FIG. 13



Cross-Section of Valley, ¾ mile South of Lindale, Floyd Co., Georgia, Showing the Position of the Manganese-Deposit and the Relations of the Underlying Rocks.

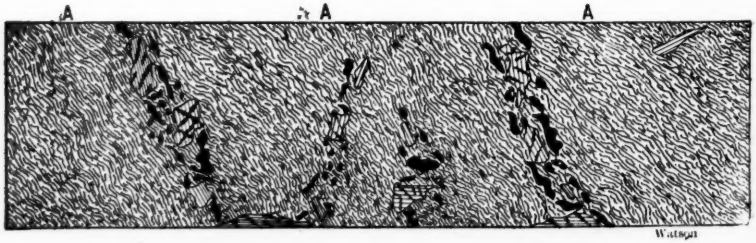
A, residual clay, containing admixed chert and partially decayed rock-fragments; B, Knox dolomite; C, Conasauga shale. The black area is manganese.

highly siliceous and freely mixed with large and small chert-fragments, usually in an advanced stage of decay. The clays usually show partial stratification, the bedding planes conforming in a general way with the ridge-slope. They thin toward the top of the ridge and are the thickest in the valley.

The ore is distributed through the clay in the form of

stringers and masses only a few inches in thickness, which cut the clay in all directions, conforming at times with the bedding-planes. Many of the stringers are composed of quartz, around and along which the ore is deposited as impregnations, incrustations, and as nodules and gravel. A goodly proportion of the gravel and nodular types of the ore is distributed through the clays without any apparent relation to the chert-fragments and masses. In most cases, however, the ore is closely associated with the chert, varying from impregnations as seams of knife-edge thickness to a ground-mass of ore cementing the partially fresh and decomposed chert-fragments. (See Fig. 15.) The form of breccia-ore commonly occurring in this locality is shown in Fig. 15. The proportion of chert to ore of the breccia-mass varies widely, from a mere film of manganese oxide, filling the cracks of the shattered chert and binding them together, to those in which the largest bulk of the mass is ore containing but few small chert-fragments.

FIG. 14



Section in One of the Openings at the Lindale Mine, 4 Miles South of Rome, Georgia, Showing the Mode of Occurrence of the Manganese-Ores.

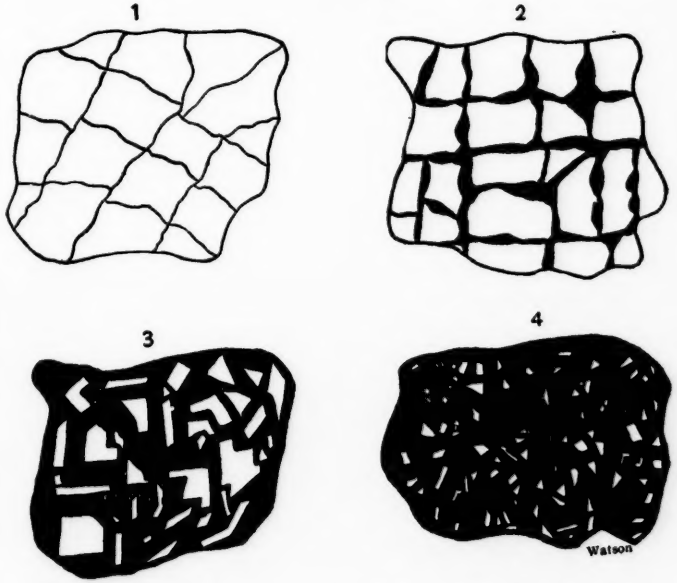
A, ore-bearing clay. The black areas are manganese. The irregular areas with straight parallel lines are fragments of chert and sandstone, the cracks of which are filled with manganese oxide.

The Tunnel Hill District.—The Tunnel Hill district includes the contiguous parts of Whitfield and Catoosa counties in the northeast part of the Paleozoic Group. In structure and topography the area quite closely resembles certain parts of the Cave Spring district already described. The rocks include shales, sandstones and limestones, and in age they range from

Cambrian to Carboniferous. Several faults of the minor-thrust type cut the rocks at close intervals. The ores are limited to the residual decay derived from an underlying long, narrow belt of Knox dolomite, marking the position of a dissected chain of ridges trending northeast-southwest. This belt of the Knox formation is included between two faults, and is in contact on the east and west sides with the Rome shales and sandstones.

In 1890, the Catoosa Mining Company made extensive preparations for mining manganese on its property, located

FIG. 15.



Drawings Illustrating the Formation of Manganese-Breccia Ore in the Lindale and Cave Spring Deposits, Floyd Co., Georgia. Manganese oxide is represented by the black lines and areas. The white areas are fragments of chert and sandstone. Attention is directed to the increase in the proportion of manganese to rock in passing from No. 1 to No. 4.

about 2 miles north of Tunnel Hill, a station on the Western and Atlantic railroad. A manganese-plant equipped with the necessary modern machinery was built, and a number of miles

of railroad were laid from the mill to the openings. Less than 30 cars of ore, including manganese and manganiferous iron-ore, were shipped.

Openings were made along the magnesian limestone ridge for a distance of 6 miles northeast of Tunnel Hill. One shaft was sunk to a depth of 210 ft. in the residual cherty clays without striking the bed-rock, and a number of others were put down to a depth of more than 100 ft. with the same result. A 150-ft. shaft is reported to have passed through manganiferous iron-ore for most of its depth.

The occurrence and character of the ore closely resemble that of the Cartersville district. The ore is mostly composed of botryoidal or kidney-shaped nodules, ranging from 1 to 12 and more in. in diameter, usually with a crystalline interior. The best exposures of the ore were observed in the cuts near the northern limits of the property.

The openings nearest Tunnel Hill show brown hematite and manganiferous iron-ore, much of which is of the breccia-type. The brown iron-ore is in close relation with the manganese, but is more abundant, occurring in the form of pockets and lenticular layers as much as 20 ft. thick. The manganese and iron occur in many places admixed as manganiferous iron ore; at other places they occur as separate and distinct ores in the same deposit; and at others still they occur as separate deposits without any admixture of each other.

Origin of the Manganese-Ores in the Paleozoic Area.

The stratigraphic position of the ores has been shown to be in the decay derived from and resting on three different formations belonging to the Cambro-Silurian, namely, the Weisner quartzite, Beaver limestone and Knox dolomite. The ores occur with about equal frequency in the decay derived from the three formations.

The character and depth of the decay and mode of occurrence, including distribution, of the ores in the clay, have already been described in some detail, and need not be repeated here. While faulting is a characteristic structural fea-

ture of the region, the distribution, occurrence and nature of the ores preclude any connection or relationship to these lines of breakage. The region is, furthermore, one of extensive and closely associated ore-deposits of different mineral types, and each type is of considerable commercial importance. These have been separately and independently studied by different geologists in recent years, and while the deposits are closely associated, they have been shown to bear no genetic relationship to each other. It is necessary here to make clearer this association of deposits.

The more important associated deposits consist of brown iron-ore, yellow ocher and bauxite. The deposits of iron-ore all contain traces of manganese, and most of the manganese contains traces of iron, but the principal deposits of the two metals are quite distinct from each other. According to origin several distinct types of limonite or brown iron-ore occur in association with the manganese in the Paleozoic area, grouped by Hayes [1] as (1) Gossan-ores; (2) Tertiary gravel-ores; (3) Concentration-deposits; and (4) Fault-deposits. Other forms of iron-ores occur, but they are of less importance within the immediate manganese districts. Only the concentration and fault-deposits concern the discussion of the genesis of the manganese accumulation.

Hayes refers to the concentration-deposits of the Cartersville district as follows: [2]

"At various times these valleys [limestone] have received the drainage not only from the adjacent quartzite and limestone, but probably, also, from other of the valley formations; and the widely disseminated iron leached from these formations during the process of decay has been transported to the limestone valley, and there concentrated upon the underlying impervious quartzite."

The principle underlying the genesis of the concentration-deposits is well expressed in the following sentence by Hayes: [3] "They may occur wherever a limestone is underlain by an in-

[1] *Trans.*, xxx., p. 411 (1901).
[2] *Ibid.*, pp. 412-413.
[3] *Ibid.*, p. 412.

soluble and impervious stratum, such as sandstone or quartzite." He further says:[1]

"Favorable conditions for this accumulation occur in northwest Georgia and Alabama, at the contact of the lower Carboniferous limestones with sandstones which sometimes underlie it, and at the contact of the Beaver limestone with the underlying Weisner quartzite."

The second type of iron-ore deposits of the area is that genetically related to the faults which intersect the strata and are designated by Hayes as fault-deposits.

The yellow ocher-deposits are closely associated with those of manganese in the Cartersville district; and also with the iron-ores of the same area. Beginning at a distance of about 3 miles southeast of Cartersville, the ocher-belt has a northward extension of 7 to 8 miles, confined exclusively to the Weisner quartzite, which has been greatly fractured and faulted. The occurrence of the ocher is entirely in the nature of replacement-deposits in the shattered quartzite,—the silica of the quartzite having been removed in solution and the hydrated ferric oxide substituted.[2]

The last type of ore-deposit in the area that needs mention is bauxite. The ore-bodies are distinct pocket deposits, having the vertical and lateral dimensions about equal, and they are inclosed in the residual clays derived from the decay of the Knox dolomite. They were first shown by Hayes,[3] and afterwards corroborated by the writer,[4] to represent accumulations of hydrated aluminum oxide in vents or springs along the lines of numerous faults which intersect the area. The source of the alumina was from below, in the underlying aluminous shales of the Conasauga (Cambrian) formation, and was taken in solution by hot ascending acidulated waters circulating along the lines of fracture.

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[1] *Ibid.*, p. 412.

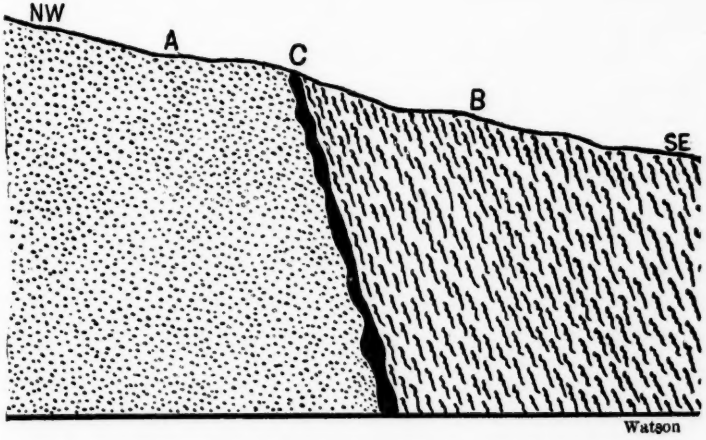
[2] *Ibid.*, pp. 415-418.

[3] Hayes, C. W., *Sixteenth Annual Report U. S. Geol. Survey*, 1895, Part III., pp. 587-591.

[4] Watson, Thomas L., *American Geologist*, 1901, vol. xxviii, pp. 25-45.

Enough detail has been given to show the non-relationship genetically between the manganese and the other ore-deposts. We must look, therefore, to an independent theory for the genesis of the manganese. The theory which best accords with the facts as the writer has interpreted them is, with some modification, that essentially outlined previously by Penrose.[1] It

FIG. 16.



Section through the Stratham Tract, near Draketown, Georgia, Showing Mode of Occurrence of the Ores.

A, banded quartzite with magnetite and some pyrite; B, decayed mica-schist, in which the planes of schistosity are perfectly preserved; C, ore, including manganese and manganiferous iron-ore, magnetite and limonite.

satisfactorily explains (1) the source from which the manganese was derived; (2) the method of solution, transportation and precipitation of the manganese; and (3) the process of its local accumulation.

1. *Source of the Manganese.*—The immediate source of the manganese was from the rocks from which the residual decay inclosing the ores was derived by weathering. Accumulation was not entirely limited, perhaps, to the manganese contained

[1] Penrose, R. A. F., 'Manganese: Its Uses, Ores and Deposits,' *Annual Report Geological Survey of Arkansas*, 1890, vol. i., p. 539 *et seq.*

in any single formation in whose residual decay the ores now exist, but was derived from any formations containing this element, formerly covering the one in which the ores are now found. There is field-evidence in certain areas to support this statement.

As shown from the general geologic distribution and mode of occurrence of the ores discussed above, the source of the manganese could not have been from rocks underlying those in whose residual decay the ores are now inclosed.

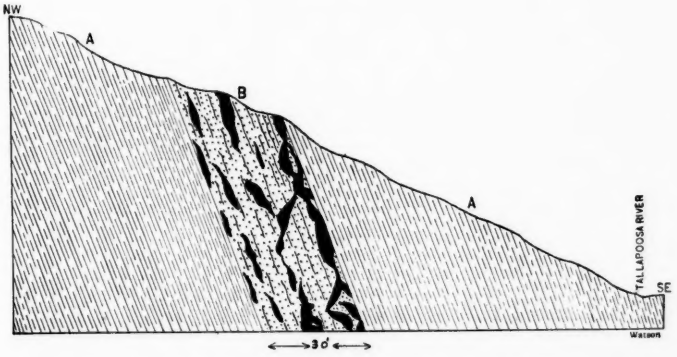
Microscopic study of a number of thin sections prepared from hand-specimens of the quartzite, collected by the writer from all parts of the quartzite area, failed to disclose any mineral substance that could be definitely referred to manganese in any mineralogical form. In order to further test the absence or presence of manganese in the quartzite, large fragments were chipped from each hand-specimen, mixed and powdered as one sample. From this bulk of powdered quartzite, a sample was carefully taken and subjected to a chemical analysis, searching particularly for manganese. The analysis showed no manganese (see analysis on page 161), which confirms the microscopic study. It would not be safe to conclude from a single analysis, though made from a sample prepared from hand-specimens of the rock taken over all parts of the area, that manganese was entirely absent from the formation. When added, however, to similar results from microscopic study, the two greatly strengthen such an inference. If these results should later prove conclusive, the source of the manganese in the decay of the quartzite must then have been from once-existing overlying formations, from which, upon weathering, the manganese was concentrated by chemical and physical conditions obtaining; or, else, the manganese now found in the decay of this formation was originally limited to that part of the formation reduced to decay.

The Paleozoic rocks are bordered on the east and south in Georgia by older crystalline rocks from which the former rocks were largely derived. These crystalline rocks, made up in part of original igneous masses and in part of original sedimentaries,

are composed of numerous complex manganese-bearing silicates. It was from these older crystalline rocks, during decay, that the manganese is believed to have been originally derived.

2. *Solution, Transportation and Precipitation of the Manganese.*—Assuming that the original source of the manganese

FIG. 17.



Section through the Westbrook Tract, Paulding Co., Georgia, Showing the Mode of Occurrence of the Ores.

A, mica-schist, partially decayed, highly schistose; B, banded quartzite, 30 ft. wide, cut by quartz-stringers containing the ore, which includes manganese, manganiferous iron-ore and magnetite.

was from the older crystalline rocks to the east and south, it remains to show how the manganiferous material reached its present form and position.

The crystalline rocks of Georgia are composed chiefly of granites, gneisses, schists and basic igneous masses, and they are everywhere deeply decayed,—buried under a thick covering of their residual clays. The essential minerals in these rocks are silicates, many of which are manganese-bearing. Decay in this southern region has been promoted largely by chemical changes in the mineral constituents of the rocks, resulting in mineralogical combinations of simpler and more stable form, totally different from the original forms. The combined action of atmospheric oxygen, water, carbonic and organic acids, and to a less degree, perhaps, certain inorganic acids, has been the

principal agent involved in the chemical decay of the rocks. Accompanying such changes, the metallic bases of the silicates combine with the various acids and are removed in solution as salts of these acids, the insoluble parts of the minerals remaining where formed, to make up the residual mantle. Manganese, with other of the base-forming elements, is thus removed in solution by the streams, and under favorable conditions of oxidation finally precipitated with the sediments on the floor of the water-bodies into which the streams drain.

Definite evidence from field-study in this area, by the writer, is lacking to indicate the exact form in which the manganese was laid down in the rocks, whether as carbonate or oxide or both.

After examination of the chemical behavior of manganese, Dunnington [1] calls attention to the probability of manganese-sulphate having taken an important part in the formation of deposits of manganese-ores. In view of the results from this examination he says: [2]

"It appears possible that many deposits of manganese in calciferous rocks owe their formation to the action of solutions of sulphates, and possibly an illustration of such action is presented in the manganese-deposits of Crimora, Augusta county, Virginia. . . ."

Professor Dunnington then outlines the conditions under which he conceives the Virginia deposits to have been formed.

3. *Local Accumulation of the Manganese.*—If, as indicated, the manganese was regularly or irregularly disseminated in a finely divided state through the limestones and quartzite in a greater or less quantity, then some secondary action or process must explain their present local accumulation. Segregation to any appreciable extent, if at all, of the finely disseminated particles of manganese does not appear to have taken place in the original unweathered rock. The agencies which promoted the decay of the rocks inclosing the manganese particles were

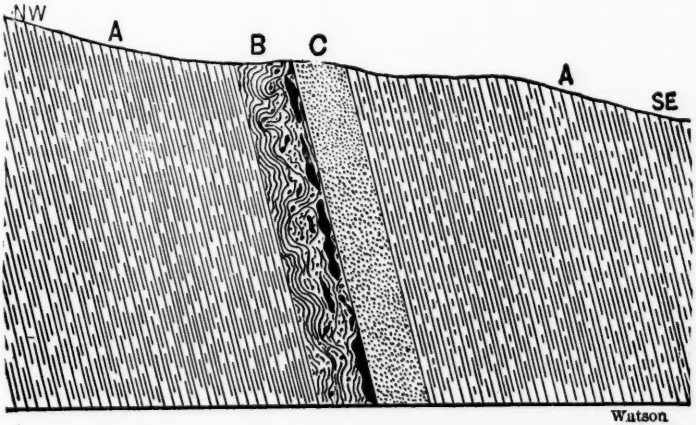
[1] Dunnington, F. P., "On the Formation of Deposits of Oxides of Manganese," *Amer. Journ. Sci.*, 1888 (3 s.), vol. xxxvi., pp. 175-178.

[2] *Ibid.*, p. 177.

those involved in the accumulation of the ores in their present concentrated form. The process involved in the local accumulation was largely one of resolution of the manganese by the acidulated surface-waters and its reprecipitation in another position in the residual clays.

The irregular distribution of the ores, both laterally and vertically, in the residual clays; the frequency with which the ore-bodies are observed to cut across the bedding of the inclos-

FIG. 18.



Section through the Blue Ridge Mine, Fannin Co., Georgia, Showing the Mode of Occurrence of the Manganese and Iron-Ores.

A, partially decayed mica-schist, grading into quartz-schist in places; B, manganese and iron oxides, distributed through the decay of the mica-schist. The black dots and areas are the ores; C, jasper-like qnartz.

ing clays, and without regard to orientation in any direction; the invariable presence of greater or less quantities of included quartz-grains and other particles of siliceous material irregularly distributed through the nodules and masses of ore, of the same character as that composing the inclosing clays; the concretionary nodular and stalactitic forms of the ore; and its prevailing tendency to crystalline structure, are the most pronounced features of the ores, and are those which would result from such a process of segregation as outlined. That is, they

are secondary accumulations, resulting from chemical and physical action during the decay of the rocks containing the manganese.

Abundant masses of breccia-ore are associated to some extent with other types of the ore in all deposits, but they are especially characteristic of the lower zone of decay of the quartzite, which consists of only partially-decayed and broken masses of the rock over the quartzite area. The formation of the breccia-masses is due to the downward percolation of the manganiferous solutions through the overlying mantle of decay into the cracks and crevices separating the rock-fragments and deposition of the manganese oxide. In the Cave Spring district, where broken masses and beds of chert from the Knox dolomite abound, a similar formation of chert-breccia is observed. In some instances the percolation from above has extended into the cracks of the moderately fresh rock below, with deposition of manganese forming intersecting veins in the rock.

The frequent black color of the ore-bearing clays especially noticeable near the ore-bodies, due to the presence of very finely-disseminated particles of manganese oxide, finds explanation in the precipitation of the manganese oxide from the permeating solutions. All of these associations and different types of the ore are regarded as products of secondary chemical and physical action.

Finally, this process of local concentration of manganese has its analogy in the present accumulation of manganese in the residual decay of the crystalline rocks throughout the Southern Appalachians. The writer has observed in his field-study of rock-weathering, in parts of Virginia, the Carolinas and Georgia, that, in the weathered materials of these rocks, some of whose minerals were manganese-bearing, the decay was colored black in spots from the oxide of manganese, and, frequently, knife-edge stringers of the manganese were found filling the cracks in the clays.

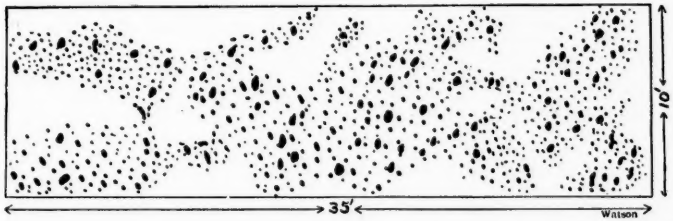
The theory as outlined above is not new, but was previously elaborated in greater detail by Prof. Penrose in his ex-

haustive and excellent volume on manganese.[1] The only point of difference between Prof. Penrose and myself, as to the Georgia ores, is that of the occurrence of some of the ore-bodies in the residual clays occupying similar positions in the original fresh rock, as stated by Penrose. The writer has not observed a single occurrence of the ores in the fresh rock in the Georgia area.

II. MANGANESE-DEPOSITS OF THE CRYSTALLINE AREA.

The position of the Crystalline area is shown on the accompanying map (Fig. 1). The area includes two physiographically distinct provinces, namely, the Appalachian mountains and the Piedmont plateau. The transition in the rocks of the plateau, along its northwest margin, to those of the mountain province

FIG. 19.



Section along the South Face of the Large Opening on the Lowe Tract, near Cave Spring, Floyd Co., Georgia, Showing the Occurrence of Manganese "Pellet"-Ore in the Residual Clay.

Black dots indicate the "pellet"-ore; white areas, deep red-brown clay derived from the Knox dolomite. No admixed chert-fragments or nodular ore contained in the clay at this point.

is indistinctly marked and is not sudden, but is, usually, gradual. Topographically, the exact limit between the two is equally difficult to define, since the elevation of the plateau near the border of the Appalachian mountain province is not sharply contrasted with that of the southeast margin of the latter province, but the slope of the one gradually passes into that of the other.

[1] *Annual Report Geol. Survey of Arkansas*, 1890, Vol. i, p. 539 *et seq.*

The Crystalline area forms the middle belt of the State (Fig. 1). It is separated on the southeast from the Coastal Plain by the fall-line, and on the northwest it is separated from the Paleozoic area by the Cartersville fault. Its axis has a general northeast-southwest trend, and, with the exception of the extreme ten northwest counties, it occupies the entire north part of the State.

Rocks of the Crystalline Area.

With but few exceptions, the rocks of the Crystalline area include profoundly altered, original clastic and igneous masses —crystalline-metamorphic rocks. Some of the granites and most, if not all, of the more recent basic dike-rocks retain in the field their original characteristic massive structures.

Many different mineralogical types of rocks are represented. Metamorphism has been so complete in many that it is often impossible to say, with certainty, whether they were derived from original sedimentary or igneous masses. Granites, gneisses, schists, slates, limestones and quartzites or sandstones compose the principal rocks. These are cut by numerous intrusions of more recent basic igneous rocks in the form of dikes. Diabase, diorite and gabbro comprise the commonest types of dike-rocks. Hornblende- and mica-schists are the most widespread of the crystalline schists. The granites and a part of the gneisses are mica-rocks.

The entire Crystalline area is one of great complexity. The rocks are everywhere altered, intricately folded and tilted, and secondary structures induced in them. A further result of the intense metamorphism is the formation of numerous secondary minerals. The structural and age relations of the rocks of the area have not yet been worked out. With but few exceptions the rocks are geologically old, and belong to different periods of formation; some are pre-Cambrian, while others are of later age.

The Rock-Forming Minerals of the Area.

The rocks of the area comprise most of the more common rock-forming minerals and many of the rarer ones. The source

of the manganese in the crystalline rocks of the State is chiefly from the various silicates containing manganese as one of the base-forming elements. Upon decomposition of the complex silicates, the manganese is either removed in solution in the form of a soluble salt and deposited with the sediments formed elsewhere, or it is retained in part or in whole in the form of the insoluble oxide distributed through the residual decay of the original rock, *in situ.* Numerous manganiferous silicates are distributed through the rocks of the Georgia Crystalline area, among the commonest of which are certain species belonging to the amphibole, pyroxene, mica, garnet, epidote or olivine groups. Besides the silicate form of manganese, the writer has observed both the carbonate and oxide of manganese in several localities in the crystalline rocks of Georgia.

Rhodochrosite is found in Towns county, 2 miles west of Hiawassee, associated with the oxides of manganese and iron in hornblendic rocks of the corundum belt. Manganese oxide, in association with small grains and crystals of magnetite, occurs in a magnetite-quartzite schist in Haralson and Paulding counties.

Residual Decay of the Crystalline Rocks.

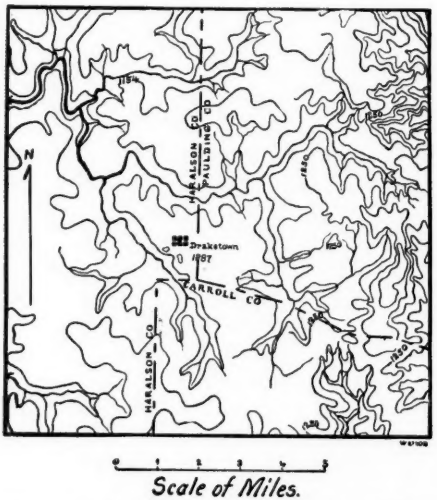
Atmospheric forces have been continuously operative on the rocks of the Crystalline area of Georgia for an indefinite period of time, resulting in the fresh rock being buried at present under a considerable depth of residual decay. Consequently, exposures of the fresh rock from which the decay was derived are seldom seen except on the steeper slopes and along the stream-courses. The mantle of decayed rock varies greatly in thickness, from a few feet to several hundred feet. Its character is equally variable, dependent mainly upon the type of rock from which it was derived and the forces promoting it.

Mode of Occurrence of the Manganese-Ores.

The lithological associations and modes of occurrence of the manganese-ores are different from those of the Palezoic area.

The ore is usually massive and often fine-granular, admixed or otherwise closely associated with iron, and is less often of the gravel and larger concretionary nodular types so characteristic of the Cartersville district and other of the Paleozoic area-deposits. Of the former occurrence the locality to the northeast of Cohutta Springs, in Murray county, and that of the Drake-town district, in Haralson and Paulding counties, are perhaps the most typical. Near the Tennessee line, in the northeast part of Murray county and 5 to 6 miles northeast of Cohutta Springs, the manganese occurs as small nests or pockets in extensive beds of iron-ore in the Ocoee (pre-Cambrian) quartzites and slates. The manganese is not entirely free from iron, and much of it is a manganiferous iron-ore of apparently homogeneous composition.

FIG. 20.



Topographical Map of the Darketown District, Georgia. (Tallapoosa and Marietta Topographic Sheets, *U. S. Geol. Survey.*) Contour-interval, 100 ft.

The ore of the Draketown district in Haralson and Paulding counties is either massive or minutely-divided manganese oxide, in a finely-banded quartzite or sandstone intercalated with mica-schist. The siliceous rock is heavily charged with

small grains and crystals of manganiferous magnetite and separate grains of manganese oxide, and in places the rock is pyritiferous. The manganese is mostly concentrated along the contact between the quartzite and schist, but contained mostly in the quartzite as massive ore carrying usually much iron, which at times almost totally replaces the manganese. (See Figs. 16 and 17.) Between the two extremes of manganese-ore containing a little iron and iron-ore with a little manganese, all degrees of admixture of the two oxides occur.

The nodular type of ore similar to that of the Cartersville district is, perhaps, best developed in the manganese-deposits occurring within the southern limits of the town of Blue Ridge, in Fannin county. (See Fig. 18.) Here the manganese is found in the residual clays derived from the decay of mica-schist near the margin of a narrow band of jasper-like quartz, which cuts the schist in an approximate north-south direction. The manganese is distributed through the clays as gravel, nodules and larger masses in nests or small pockets and stringers. The ore contains much siliceous impurity, and is in intimate relation with iron-ore, much of which has been shipped.

At other localities in the Crystalline area manganese is found, in massive and nodular forms and as a black clayey mixture of finely divided manganese oxide, in residual clays derived from the decay of hornblende- and mica-schists. The mica-schist is often garnetiferous.

The above occurrences of manganese in the crystalline rocks indicate (1) a concentration of the ore along and near the contact between certain formations; and (2) accumulation of the ore in the residual clays derived from the decay of various siliceous crystalline rocks.

Mineralogical Forms of the Ores.—The silicate, oxide and carbonate of manganese are found to some extent in the rocks of the Crystalline area. Neither the silicate nor the carbonate is of commercial importance. Manganese-bearing silicates are widely distributed among the more common rock-forming minerals of the area, and are of great importance in that they form

the source, on decay, of the workable deposits of manganese in the form of the oxide. In several localities the oxide is found, in place, in the fresh rock, but, usually, it is a secondary product inclosed in the residual clays, similar to the ores of the Paleozoic area. The manganese of both the Crystalline and Paleozoic areas of Georgia include only the oxides of the metal.

Extent of the Work and Location of the Deposits.—More or less prospecting work for manganese-ores has been done in a number of counties in the Crystalline area. The test-work has been sufficient in most cases to indicate that workable deposits of the ore do not exist, although small shipments of the ore have been made from a number of the openings in different counties.

The localities in which prospecting work has been done for manganese are widely separated and are scattered over various parts of the area which bear no apparent geological relationship to each other. The deposits are not associated with any particular type of rock, but are found in association with several widely different mineralogical types.

The counties in which manganese has been worked or tested in the Crystalline area are Murray, Fannin, Towns, Cherokee, Haralson, Paulding, Habersham and Hart. See map (Fig. 1), which shows the distribution of the ore-deposits.

Genesis of the Ores in the Crytalline Area.

Numerous openings made for manganese in different parts of the Crystalline area afforded opportunity for tracing the formation of the manganese oxides from several of the manganese-bearing silicates. Of these a manganiferous garnet and mica showed the formation of the oxide from the original silicate in both a partial and complete stage of decomposition. In each case the early stage was indicated by the original mineral being irregularly coated and spotted from decay by a mixture of the oxides of manganese and iron. The final stage showed the almost complete destruction of the original mineral, and its place filled by the black amorphous oxides of manganese and

iron. More or less stain from the oxides had extended beyond the limits of the original manganese-bearing silicate, discoloring the inclosing clays.

The source of the manganese in the Crystalline area has been mostly, if not entirely, from the various manganese-bearing silicates, which enter largely into the composition of most of the rocks. By the decomposition of the minerals composing these rocks, the base-forming elements either form soluble salts of inorganic and organic acids promoting the decay, and are removed in solution, or else the whole or a part of certain of the base-elements are converted into insoluble oxides and retained, *in situ*, to form the mantle of residual decay. In either case the process may result in the removal by solution of only a part of certain of the base-elements, iron and manganese, in the form of soluble salts, while the remainder of the same elements is retained as insoluble oxides in the residual decay. Both reactions are common in the surface zone of oxidation, as proved by recent work in rock-weathering.

Recent investigations in rock-weathering show that iron is frequently retained in the residual clays in amounts larger than that of any other constituent in proportion to the percentage amount present in the fresh rock. A loss, however, by removal in solution, in the form of a soluble salt on decay of the rock, is often shown in the iron. So far as investigation has gone, the iron is not entirely removed in any case, but a part of it remains in the form of the insoluble oxide. A like tendency is indicated for manganese when present in those rocks so far investigated.

Upon subsequent chemical and physical changes, the manganese is further concentrated in the residual clays, and the accumulation of the oxide is sometimes in quantity sufficiently large to be of commercial value.

Some of the manganese-deposits of the Crystalline area indicate that the ore has been leached from the surrounding rocks upon decay and concentrated in the clays along the contact-zones of certain formations. In only one locality in the Crystalline area, namely, the Darketown district of Haralson and Paulding

counties, has manganese been found in the form of the oxide, in place, in the original rocks. The manganese exists here partly as the free oxide in a banded quartzite, and partly as a manganese-bearing magnetite which forms a considerale percentage of the rock in places. Concentration of the manganese with iron has taken place near the margin of the quartzite in contact with the mica-schist, in quantity sufficient to yield a small amount of workable ore.

Accompanying the process of rock-decay the retention of manganese in more localized form has been promoted in places. The process is still in progress, and, accompanying it, the accumulation of manganese in those places where the conditions are favorable.

Briefly stated, then, the manganese-ores of the Georgia Crystalline area represent the secondary accumulations of the insoluble oxides of the metal supplied from the manganese-bearing silicates on decomposition, and subsequently concentrated and localized in the residual clays derived from the decay of the underlying siliceous crystalline rocks. In places, accumulation of the oxides has progressed along and near contact-zones in the rocks; in other places concentration has been in the clays and removed from contacts.

Methods of Mining the Ore.

The nature of the ore to be mined in the Georgia area is one of irregular distribution, in the form of nodules and pockets, through residual clays, which range in thickness from 25 ft. to several hundred feet. The ore-distribution varies greatly, and the deposits are limited both in depth and lateral extent; hence, the methods for operating in one place will necessarily vary, more or less, in detail from those in another. As a rule, the deposits are located on the summits and higher slopes of the hills and ridges, though there are many exceptions, for they not infrequently occupy the lower slopes and valley-bottoms.

The method of mining will depend largely upon the location of the deposits and their depth below the surface. Open

pit and cut, shaft and tunnel work are employed. These are often used together, to advantage, in the same place, especially where the ores begin at or near the surface and continue irregularly to some depth below. In such cases, open pit and cut work is used, and, from the bottom of the open work, shafts are sunk and drifts are run at different levels from the shafts. Tunneling becomes necessary in most of the steeper slope-deposits. In the lower deposits, especially those of the valley-bottoms, shafting and tunneling is most advantageously employed. In most cases of tunneling and shafting it becomes necessary, from the nature of the clays, to timber the openings in order to prevent caving. The timbering over most of the Georgia area has been poorly done, and, in many cases, put in to meet only temporary needs.

Expensive and heavy machinery is unnecessary, and the equipment should be as light and portable as possible, so that moving from one place to another, as the ore becomes exhausted, can be done speedily and at a small cost.

Preparation of the Ore.

The occurrence of the ores in the residual clays means, usually, more or less admixture of the ore with clay. Usually, the only treatment of the ore necessary before shipping is to free it from the adhering clay. Crushing and jigging are necessary in the spongy or porous type of ore, the numerous cavities of which are filled with the clay; also in those ores containing considerable free-quartz grains and cemented fragments of the rock. This is especially true of much of the breccia-ore, which is rendered marketable by materially reducing the amount of siliceous material in this method. Washing will usually suffice for cleansing the bulk of the ore. In the crushed and jigged ore, subsequent washing is also necessary.

In the early history of the manganese mining in Georgia less care was used in properly cleansing the ore than at present, and much of the ore then shipped contained large quantities of adhering clay and other extraneous material. The principal and, frequently, the only treatment was that of screening. At

that time all the washing done was by hand. The form of washer used was a revolving-cylinder perforated with holes, and fed inside by a constant stream of water. The ore was put into the cylinder through a door, the door closed and the cylinder revolved by hand until the ore was freed by running water from the clay, when the ore was removed through the same opening. The capacity of the washer was very limited, and it could be used only on a small scale. Much of the smaller ore was lost, but the larger fragments were thoroughly cleansed.

Later, a form of log-washer, similar to that used for cleansing the brown iron-ores, was introduced, and is the form of washer at present in use. Briefly, the log-washer consists of a long and stoutly-built box, of sufficient length and depth to contain the log. The box, or trough, is elevated at one end. A log or central shaft, 25 to 40 ft. long, carrying heavy iron-flanges, spirally arranged the length of the log, revolves lengthwise in the box or trough. The ore is fed at the upper end of the box, and is gradually forced by the revolving log to the lower end, where it passes out. A constant stream of water plays on the ore in the box. The constant agitation and beating of the ore by the log and the washing by water frees it from the adhering clay. Steam is the motive power.

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